FRIEDRICH AUGUST KEKULÉ

*Architect of Atoms**

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It has been said, with truth, of August Kekulé that he bridged the gap from alchemy to modern chemistry . . . Let us define alchemy.

Alchemy: The medieval chemical pseudoscience whose great objective was the transmutation of base metals into gold; the universal cure-agent for disease; the elixir of perpetual life.

Another definition found in books assumes alchemy to mean an infusion or mingling as juice or liquid, especially as extracted from plants for purpose of medicinal ingredients.

What was the world-wide state of alchemy on its road to chemistry in 1865? What was considered Chemistry? Glance at a text professing to be on the subject of chemistry at that period. You are struck at once with the absence of symbols. The shorthand scrawlings and scratchings by which thinking men transferred their thoughts were lacking, for the alchemy turned to chemistry.

Symbols for chemicals, and for chemical reactions, or, for that matter, symbols for structure, were absent—undiscovered, undefined. It was a long and devious travail. Many names are found again and again in a recital of the birth of modern symbols for chemical structure; Berzelius was one. His pupils included Wöhler who forged the chain between inorganic chemistry and organic chemistry. A name linked with that of Wöhler is von Liebig, father of Agricultural Chemistry. von Liebig had a pupil whose name was Friedrich August Kekulé.

Briefly, in a most elementary manner, we review the situation in chemistry at this period. Chemists could and did make analyses. They were able to determine the ingredients. They knew the types of elements. They could enumerate them. The plan of their union was lacking. The arrangement was missing. The blue print of organization was

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not available. Linkage became most vital to advance. No one had told about linkage. No one had given a comprehensive and working plan which could withstand criticism. No one had done this: Kekulé found the answer to the riddle in a dream.

Friedrich August Kekulé was born in Darmstadt, September 7, 1829. He showed early talent in drawing and entered the University of Giessen with the intention of studying architecture. Through Liebig's lectures which he attended at Giessen, Kekulé was first attracted to chemistry. Family opposition to his desire to change from architecture to chemistry exiled him to Darmstadt where he managed to study some chemistry. In 1849 he was permitted to return to Giessen where he studied under Will and then again, Liebig. After a year, Liebig told him that he would probably ruin his health if he tried to become a good chemist. As a matter of fact, Kekulé for many years allowed only three or four hours each day for sleep.

In 1851 came an opportunity to go to Paris where Kekulé attended lectures. One day he saw a poster which announced that Charles Gerhardt, ex-professor of Montpellier, was offering lessons in chemistry. He entered his name for these classes. Gerhardt had seen Kekulé's name in Liebig's "Letters on Chemistry." He sent for the young student and offered him the post of assistant. Kekulé did not accept. He continued for a year to attend the lectures and gave much credit later to the inspirational visits he had with his teacher, Gerhardt. Giessen conferred on him the degree of Doctor of Philosophy, July 15, 1852. Then Kekulé went to Switzerland to work with Von Planta, and later to London as assistant to Stenhouse. Kekulé's first independent publication was printed in English and had to do with valence in organic compounds (1854).

During his stay in London, Kekulé was striving to answer the riddle of linkage. The time was about 1856. A glutton for work, and always in need of sleep, Kekulé sought his way by bus to his modest lodging in Clapham Road, after an evening of discussion with his friend, Hugo Müller, in Islington. Riding atop the bus, he fell asleep. He had a strange dream. Molecules gamboled with impish glee. For the first time Kekulé was enabled to discern the nature of molecular motion; to see clearly the precise method of molecular madness. He saw diminutive atoms frequently pair off and be embraced by larger atoms. He saw still larger atoms hold three or four small atoms, while the entire group kept whirling about in a giddy dance, the large ones forming a chain. Awakened by the cry of the conductor, "Clapham Road," Kekulé spent the night transferring his reveries to paper. Out of this dream grew a system of constitutional formulas representing the structure of molecules of the open-chain type.

Kekulé was homesick in England. He wanted to teach in a German University. With this end in mind he returned to Germany and became a travelling student. In the winter of 1856 he became a dozent at Heidelberg. Here he did some of his most important work in a small private laboratory, a single room with an adjoining kitchen. He had a few pupils, among them Baeyer. It was in this little kitchen that Kekulé finished his work on fulminate of silver, and Baeyer carried out the researches on cacodyl, which subsequently became famous. After two and one-half years Kekulé received a call in 1858 to Ghent, as ordinary professor.

In this same year came "the two great treatises that have exercised so powerful an influence on chemistry—that on the constitution and metamorphosis of chemical combinations; and that on the chemical nature of carbon. We all know today that the theory of valency is the leading guide through all our science, and no one disputes that its main foundation and its eminent value in organic chemistry are primarily due to Kekulé's idea of the quadrivalency of carbon."

Kekulé put the thought forward with diffidence and only in the interest of integrity and progress. His words were, "It seems proper to communicate these conceptions, because, as it appears to me, they furnish a simple and fairly general expression for the newest discoveries, and because, therefore, the use of them may assist in the discovery of new facts."

In his celebrated Textbook of Organic Chemistry (1859), he insisted upon the facts (a) that carbon is uniformly quadrivalent in organic compounds, and (b) that carbon atoms have the remarkable power, unshared, except in a very limited degree by those of other elements, of linking up together to form chains. This idea, which now seems axiomatic, was then highly original. It was scarcely implied in the older theories and was indeed rather foreign to their point of view. Once grasped, however, it gave the key to the constitution of all organic compounds.

It was not Kekulé, however, who first used the bonds with which we are now so familiar. The complete analysis of organic radicals down to the arrangement of their component atoms was first attempted by a Scotsman, Archibald Scott Couper, in 1858. Through an unfortunate delay, Couper's contribution was not made public until a month after Kekulé had announced the theory. Because of ill health, Couper was unable to elaborate his thesis. Kekulé had a clear mental concept of the facts which were represented symbolically by Couper.

Kekulé, himself, nevertheless, did not at once begin to write graphic formulas, but rather expressed himself with great conservatism. He closed one essay with these words, "I place no more value on these views than they are worth, and I believe that much labor must still be applied before such speculations can be regarded as anything else than more or less elegant hypotheses; but I believe, too, that at least experimental speculations of this kind must be used in chemistry."

In 1859, Kekulé began to construct graphic formulas, but did not employ Couper's bonds. He drew pictures of atoms of different sizes to represent different degrees of "atomicity" or valency. Kekulé used curious diagrams (Kekulé's sausages) with which we are all familiar. This unwieldly notation was very short-lived, for in 1865, Crum Brown introduced the system, in which each "valency" or unit of combining power is indicated by a line. Thus Kekulé's sausages for oxygen and carbon were represented by Crum Brown by the –O– and $-\overset{|}{\underset{|}{C}}-$ which we all know. This is a more elegant and equally intelligible device. By 1865, Kekulé had adopted bonds.

In 1861, appeared the first portion of Kekulé's great textbook which emphasized and illustrated the new views with hundreds of examples. The foundations of modern organic chemistry were therein laid. What is more important, the date marks the time when the great contribution of organic chemistry to the historical development of the science as a whole was fully rendered. The earlier theory had broken down because it had failed to explain the reactions of organic chemistry. Slowly and laboriously through the stages of type theory, there had grown up in organic chemistry the theory of structure which was now destined to become dominant in its turn.

Thus we may assume that Kekulé accounted for the straight chain series of paraffin hydrocarbons. He had linked the carbons with each other. He had developed some building plans. He had not yet formed the three dimensional concept which brings us to organic chemistry.

The architect that his family had hoped Kekulé would become was yet to build.

Let us contemplate discoveries by Kekulé relating to the benzol-ring compounds. His influence and his fundamental ideas disclosed the nature of whole classes of compounds which have been of unusual interest to the people of the world ever since.

Benzene substances had originally received this name on account of a peculiar odor possessed by certain representatives. Later it was found that most compounds so classified exhibited very different properties from those of other organic substances of apparently similar structure. Kekulé found it impossible to devise an ordinary chain formula for its molecule. The constitution of benzene became of fundamental importance. At last it occurred to Kekulé that a consistent explanation was to be found in the assumption that the six carbons of benzene were arranged in a ring united by alternate single and double bonds, and with a hydrogen attached to each carbon. There is a distinct interest in Kekulé's account of how the idea came to his mind:

"I was busy writing on my textbook but could make no progress—my mind was on other things. I turned my chair to the fire and sank into a doze. Again the atoms were before my eyes. Little groups kept modestly in the background. My mind's eye, trained by the observation of similar forms, could now distinguish more complex structures of various kinds. Long chains here and there more firmly joined; all winding and turning with a snake-like motion. Suddenly one of the serpents caught its own tail and the ring thus formed whirled exasperatingly before my eyes. I woke as by lightning, and spent the rest of the night working out the logical consequences of the hypothesis. *If we learn to dream we shall perhaps discover truth.* But let us beware of publishing our dreams until they have been tested by the waking consciousness."

Kekulé thus conceived the idea that in the molecule of benzene the six carbon atoms, instead of forming an open chain, have joined together to form a six-membered ring. The formula is now in any standard chemistry textbook.

Kekulé put forward his well-known benzene theory in 1865. It has been pronounced the crowning achievement, in his hands, of the doctrine of the linking of atoms. It is held to be the most brilliant piece of scientific prediction to be found in the whole range of organic chemistry. The conception of closed chains, or cycloids, which Kekulé introduced, has shown itself to be capable of boundless expansion.

Kekulé went to the University of Bonn, in the fall of 1867. He finished his first volume of Chemistry of the Benzol Derivatives in the same year. From 1880 to 1887 occurred the publication of the second and third volumes, first as single numbers, prepared with the help of co-workers.

Kekulé always acknowledged the influence of Liebig, Odling and Williamson. Kekulé always distinguished himself as a brilliant and daring thinker, especially devoted to organic chemistry. This branch of the science is indebted to his inspiration for many of its fundamental assumptions. His students spoke of his teaching as lucid; his thinking was called luminous, as well as accurate and concentrated. His language was apt. His delivery was easy and natural. His personality was genial; his humor, happy. He never tolerated slovenly or sloppy work.

His latter years were not productive. Those close to him believed that it was because his researches did not appear to him to be complete. His sense of "finish" and his fastidiousness restrained him from publishing much which he realized fell short of his ideal. Kekulé's greatest service to chemistry remains the development of the theories of molecular structure.

Kekulé died July 13, 1896. His influence lived beyond him. His concept of the carbon ring structure had been truly born of genius. It exercised an influence on all forms of chemistry. Benzene became more than a plaything of science. Modern foundations of constitutional chemistry lie imbedded in the dreams of Kekulé. Researches which Kekulé carried on in his primitive laboratory called for further study with tools fashioned from the results of those early works. In the words Marsh quoted from Landrelt, president of the German Chemical Society at Berlin, on the announcement of the death of Kekulé: "This news will be received with sorrow not only by our society but by the whole chemical world. . . . The works which Kekulé has left behind him belong, as we all know, to the basis of all chemistry."

The constant study of the aromatic compounds in the laboratories of the world during the intervening years has served to confirm Kekulé's hypothesis, which may be considered one of the most thoroughly tested generalizations of science. If we remember that perhaps half the total number of organic compounds at present known are derivatives of benzene we shall form a just estimate of the value of Kekulé's work.

Let us remember that the side-chain theory of Paul Ehrlich may be traced to the studies of Kekulé and Perkin. The Wassermann serology studies owe their existence to the work of Ehrlich. Salvarsan and its counterparts are due directly to the advances made by Kekulé on the benzene ring structure. The latest tools of mankind against disease, the chemotherapeutic remedies of the sulfonamid group owe their existence in their turn to the dye chemistry of Ehrlich.

On the other side of the ledger, we mention poison gas; death-dealing explosives; incendiary bombs. The dreams of Kekulé—what if they had never been translated into molecules dancing in the fertile brain of the boy who became an architect of atoms instead of bricks!